

# Multiphoton detection of THz frequency light with a bilayer Graphene-Based optical platform

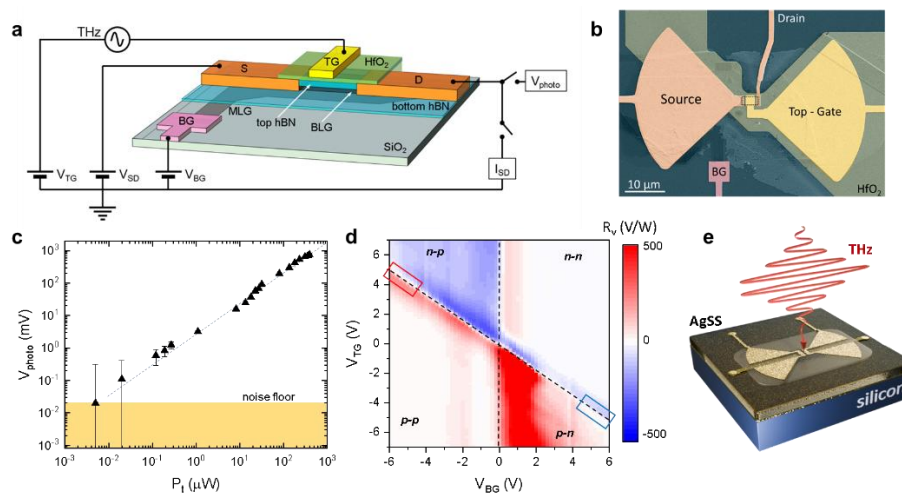
Leonardo Viti<sup>1</sup>, Lili Shi<sup>1</sup>, Kenji Watanabe<sup>2</sup>, Takashi Taniguchi<sup>2</sup>, Miriam S. Vitiello<sup>1</sup>

1. NEST, Istituto Nanoscienze – CNR and Scuola Normale Superiore, Piazza San Silvestro 12, Pisa, 56127, Italy

2. National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

**Abstract:** Detection of 3 THz radiation by tunnel field effect transistors based on bilayer graphene – hexagonal boron nitride heterostructures. We achieved noise equivalent power  $\sim 1 \text{ pWHz}^{-1/2}$  with a power dynamic range exceeding five orders of magnitude.

The realization of efficient detectors in the Terahertz (THz) spectral region is a key requirement for advancing quantum photonics and sensing technologies. However, the low photon energies and weak light–matter interaction in this range pose significant limitations, further worsen by thermal noise contributions. Two-dimensional (2D) material platforms offer a promising route to overcome these challenges, as their electronic and optical properties can be engineered to activate multiple detection mechanisms within a single device architecture [1]. In this work, we develop antenna-coupled tunnel field effect transistors (TFETs) [2] based on hBN-encapsulated bilayer graphene (BLG) for THz detection with performances compatible with the investigation of quantum correlation effects in heterostructure lasers. In these devices, the photoresponse originates from the formation of a gate-tunable tunnel junction along the channel, induced by an out-of-plane electric field that modulates the BLG bandgap and enhances the transconductance. We fabricated and characterized TFETs (Fig.1a,b) operating at  $\sim 3$ , THz, corresponding to typical emission frequencies of quantum cascade lasers, noise equivalent power (NEP) down to  $\sim 1 \text{ pWHz}^{-1/2}$ , while maintaining a minimum detectable power of  $\sim 5 \text{ nW}$  and a dynamic range exceeding five orders of magnitude (Fig.1c). Analysis of the electric-field dependence of the responsivity (Fig.1d) reveals the interplay of photothermoelectric, plasmonic, and tunneling rectification mechanisms [2]. By integrating an optimized electromagnetic coupling strategy based on an antenna-coupled Salisbury screen (Fig.1e) [3], we foresee a significant enhancement of the detector responsivity, leading to a 10-fold reduction of the NEP. These results provide a viable pathway toward highly sensitive THz detectors for probing quantum statistical properties of non-classical radiation in a spectral region that remains largely unexplored compared to microwave and optical frequencies.



**Fig. 1** (a) Schematic of the active element of the TFET: an hBN-encapsulated dual-gated BLG transistor. (b) False color SEM image of a four-terminals TFET coupled to a planar 3 THz bow-tie antenna. BG refers to the back-gate electrode. (c) Measurement of the TFET output signal vs. optical input power. (d) Responsivity map, showing the activation of different photodetection mechanisms. (e) Schematic view of the antenna-coupled graphene Salisbury screen (AgSS) architecture.

## References

- [1] M. Mittendorff, et al. "2D THz Optoelectronics," *Adv. Optical Mater.* **9**, 2001500 (2021).
- [2] L. Viti, et al. "Quantum sensitive, record dynamic range Terahertz tunnel field-effect transistor detectors exploiting multilayer graphene/hBN/bi-layer graphene/hBN heterostructures," *Nano Lett.* (2024). <https://doi.org/10.1021/acs.nanolett.4c04934>
- [3] L. Viti, et al. "Efficient Large-Area Graphene p-n Junction Terahertz Receivers on an Integrated Optical Platform." *Small Methods* **9**, no. 11 (2025): 2500083. <https://doi.org/10.1002/smt.202500083>